

# **Method and System for treating wastewater containing organic compounds**

## **BACKGROUND OF THE INVENTION**

### **5 FIELD OF THE INVENTION**

The present invention relates to a method and system for treating wastewater containing organic compounds. The present invention combines the advantages of anaerobic and aerobic systems for disposing organic pollutants in the wastewater, and integrates both systems with the membrane separation system to increase system efficiency and lower the costs of system installation.

## **DESCRIPTION OF RELATED ART**

Membrane biological treatment system is one the most popular technologies used in wastewater treatment in recent years. Such system employs membrane as separation medium, in which wastewater is first decomposed by microbes and then passed through a membrane by of the driving force of vacuum pressure difference to separate solids from liquids. The resulting permeate that passes through the membrane is the treated water, while sludge and other solid matters are entrapped in the membrane separation reactor and discharged. Reverse washing or chemical cleaning is employed to remove pollutants deposited on the surface of the membrane to prolong the membrane working life.

20 Membrane filtration is a key element of the membrane biological treatment system.

Microfiltration may be generally classified into dead-end filtration and cross-flow filtration. Dead-end filtration is similar to the conventional cake filtration where the flow of the suspension is perpendicular to the membrane surface, while solid substances are intercepted on the membrane surface and form filter cake. The thickness of filter cake is increased with the filtration volume of suspension. The flow of permeates through the membrane decreases as the filter cake thickens, which relies on the working of reverse washing cycle for cake removal from the system. In the case of cross-flow filtration, the suspension flow is parallel to the membrane surface where the cross-flow rate of suspension produces shear stress to eliminate the formation of filter cake. When the cumulative effect of the filter cake reaches equilibrium with the elimination effect, the filter cake would have constant thickness. In cross-flow filtration, there must be a rate component parallel to the membrane surface. The movement of the membrane itself or the disturbance of air bubbles can obtain such effect. For the purpose of preventing fouling so as to generate maximum permeation throughput, membrane biological treatment system typically adopts cross-flow filtration for solid-liquid separation.

In considering whether the membrane biological treatment system is economically feasible, the removal of fouling or scaling on membrane surface to prolong membrane life and lower energy loss is a key factor. Fouling refers to solid matters such as sludge, ultra fine colloid particles, and organic matters adsorbed to or settled on membrane that adds to the permeation resistance. The causes of fouling involve physical and chemical mechanisms as well as the phenomenon of concentration polarization. Scaling refers to the formation of metal crystals such as oxides, carbonates and phosphates from metals or

heavy metals. For example, in the process of anaerobic reaction, the concentration of carbonate in water increases, and if Ca, Mg, Fe or other heavy metals are present in the water, the scaling of metal carbonate on membrane surface would obstruct the membrane. Serious fouling or scaling on membrane would greatly reduce the treatment throughput.

5 Thus it is necessary to remove scaling periodically in the process of the treatment system.

In comparison with conventional activated sludge process, membrane biological treatment system requires relatively less space, and is easy to operate and maintain. The sludge entrapped in the system may be held for a long time to facilitate the removal of special or not readily biodegradable pollutants and the biological sludge can be intercepted completely. Moreover, the system does not require a settler unit, thereby saving space and increasing treatment efficiency. It is also capable of entrapping polymers that are difficult to break down. Therefore, the membrane biological treatment system is particularly suitable for small and medium scale treatment of special pollutants.

Due to the advances in membrane production technology in recent years, the membrane usage life is extended, and the loading level of membrane treatment system has increased from laboratory application level to plant applications level with capacity of 10,000m<sup>3</sup>/d. The main membrane biological treatment system used Currently is aerobic membrane biological treatment system. But the installation cost of aerobic membrane treatment system has been persistently high due to the high cost of membrane. This invention combines both aerobes and anaerobes in the membrane biological treatment system to address the problems aforesaid.

## SUMMARY OF THE INVENTION

To address the drawbacks of known membrane biological treatment systems, the present invention provides a system for treating wastewater containing organic compounds, comprising:

5           an anaerobic bioreactor capable of removing organic pollutants in wastewater through anaerobic treatment process;

          an aerobic bioreactor disposed rearwardly of said anaerobic bioreactor and capable of removing residual organic pollutants in the effluent of said anaerobic bioreactor through aerobic treatment process; and

10          a membrane separation reactor disposed rearwardly of said aerobic bioreactor and capable of separating solids from liquids in the effluent of said aerobic reactor.

          In one embodiment, the aforesaid anaerobic bioreactor and aerobic bioreactor are both initially seeded with anaerobic sludge. The aforesaid aerobic bioreactor and membrane separation reactor can further comprise a device for recycling microbes from  
15   said aerobic bioreactor or membrane separation reactor to said anaerobic bioreactor so that the microbe concentration of said anaerobic bioreactor can be maintained. The aforesaid anaerobic bioreactor comprises anaerobes or facultative bacteria, preferably comprising both methaogens and facultative anaerobes. The aforesaid aerobic bioreactor comprises facultative bacteria. The aforesaid anaerobic bioreactor comprises a device for  
20   discharging sludge outside the bioreactor.

          In another embodiment, the aforesaid anaerobic bioreactor and aerobic reactor are initially seeded with anaerobic sludge and aerobic sludge respectively. The aforesaid

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membrane separation reactor can further comprise a device for recycling microbes from said membrane separation reactor to said aerobic bioreactor. The aforesaid aerobic bioreactor and the membrane separation reactor can further comprise a device for discharging excessive aerobic waste sludge into said anaerobic bioreactor and proceeding  
5 the reaction of anaerobic digestion. The aforesaid anaerobic bioreactor comprises a device for discharging sludge outside the anaerobic bioreactor. The waste aerobic sludge in said aerobic bioreactor and membrane separation reactor can further pass through an alkaline sludge hydrolysis apparatus before being discharged into the anaerobic bioreactor.

The aforesaid aerobic bioreactor can be further used as a stripper by shortening the  
10 hydraulic retention time. During the aeration, the carbon dioxide dissolved in water is stripped, resulting in an increase of pH value in water, whereby the crystals of metal carbonate (e.g.  $\text{CaCO}_3$ ,  $\text{FeCO}_3$ ), struvite ( $\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$ ) and inorganic solids (e.g.  $\text{FeS}$ ) are produced, and furthermore, such crystals or solids are inserted in the floc matrix of aerobes through bioflocculation, that the tendency of scaling on the membrane of said  
15 membrane separation reactor is decreased.

The aforesaid system for treating wastewater containing organic compounds can further comprise an aerobic pretreatment device arranged upstream of anaerobic bioreactor for removing toxic organic substances in the wastewater so as to reduce the inhibition of such toxic substances against anaerobes.

20 The aforesaid anaerobic bioreactor can further comprise denitrifying microbes.

The aforesaid membrane separation reactor can further include a gas sparging device for scouring membrane, wherein the gas is biogas or air. Scouring said membrane  
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of membrane separation reactor with biogas could lower the pH value of water by 0.2-1.0 unit as compared to the aerobic bioreactor, hence preventing the scaling of said membranes. Alternatively, Scouring with air or air plus inorganic acid (e.g. HCl) results in the same effect as that caused by biogas.

5           The membrane of membrane separation reactor can be scoured with biogas or air continuously to clean the fouling on said membrane.

Another object of the present invention is to provide a method for treating wastewater containing organic compounds, comprising the steps of:

(a) feeding wastewater containing organic pollutants into an anaerobic bioreactor  
10   where the anaerobes therein decompose the organic pollutants in the wastewater;

(b) feeding effluent of anaerobic bioreactor in step (a) into an aerobic bioreactor where the aerobes therein decompose the residual organic in wastewater and carbon dioxide dissolved in water is stripped through air stripping so that the pH value of water is increased, whereby the crystals of metal carbonate, struvite and inorganic solids are  
15   produced and inserted in the floc matrix of aerobes through bioflocculation; and

(c) feeding effluent of aerobic bioreactor in step (b) into a membrane separation reaction where solids in the water are separated to obtain effluents free of organic pollutants.

The aforesaid method for treating wastewater containing organic compounds can  
20   further comprise a step of pretreating wastewater for removing the toxic organic pollutants (e.g. phenols and aldehydes) in wastewater before step (a) such that the inhibition of such toxic substances in the anaerobic bioreactor can be reduced.

The aforesaid method for treating wastewater containing organic compounds can further comprise a denitrification procedure in step (a). The aforesaid method for treating wastewater containing organic compounds can further comprise a step of alkaline hydrolysis for aerobic waste sludge in an alkaline sludge hydrolysis apparatus before step  
5 (a) to enhance the hydrolysis of aerobic wastewater and the digestion capability of anaerobic sludge.

The aforesaid method for treating wastewater containing organic compounds can further comprise a step of scouring membrane of said membrane separation reactor with biogas or air or air plus inorganic acid so as to prevent the scaling of membrane.

10 The aforesaid method for treating wastewater containing organic compounds can further comprise a step of recycling microbes from the aerobic bioreactor and membrane separation reactor to the anaerobic bioreactor in order to reduce the loss of microbes and maintain the concentration of microbes in the anaerobic bioreactor.

The anaerobic treatment technique features high volume efficiency without  
15 installing an oxygen supply system. It reduces the cost of installation and provides the advantage of producing less sludge than that produced by the aerobic system. The present invention combines the advantages of anaerobic and aerobic systems for disposing organic pollutants in the wastewater, and integrates both systems with the membrane separation system to increase system efficiency and lower the cost. Such system may be  
20 applied in the disposal of municipal and industrial wastewater.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 shows the schematic diagram of a system for treating wastewater containing organic compounds according to the present invention.

FIG. 2 shows the flow diagram of the method for treating wastewater containing  
5 organic compounds according to the present invention.

FIG. 3 shows the chart of COD concentrations of influent of anaerobic bioreactor, effluent of anaerobic bioreactor and effluent of membrane separation reactor versus days of operation.

FIG. 4 shows the chart of pH and ORP in anaerobic bioreactor versus days of  
10 operation.

FIG. 5 shows the chart of pH, ORP and DO in aerobic bioreactor versus days of operation.

FIG. 6 shows the chart of pH in anaerobic bioreactor, aerobic bioreactor and membrane separation reactor versus days of operation.  
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## **DETAILED DESCRIPTION OF THE INVENTION**

The system for treating wastewater containing organic compounds 10 of the present invention, as shown in Fig. 1, comprises: an anaerobic bioreactor 1, which is capable of removing organic pollutants in wastewater through anaerobic treatment process;  
20 an aerobic bioreactor 2 disposed rearwardly of said anaerobic bioreactor 1 and capable of removing residual organic pollutants in the effluent of said anaerobic bioreactor 1 through



aerobic treatment process; and a membrane separation reactor 3 disposed rearwardly of aerobic bioreactor 2 and capable of separating solids from liquids in the effluent of aerobic bioreactor 2.

In one embodiment of the system 10, said anaerobic bioreactor 1 and aerobic  
5 bioreactor 2 are both initially seeded with anaerobic sludge, wherein said anaerobic  
bioreactor 1 contains anaerobes or facultative bacteria, preferably contains both  
methanogens and facultative bacteria, and said aerobic bioreactor 2 contains facultative  
bacteria. In this embodiment, said aerobic bioreactor 2 and membrane separation reactor 3  
can further comprise a device for recycling microbes from said aerobic bioreactor 2 or  
10 membrane separation reactor 3 to said anaerobic bioreactor 1 such that the microbe  
concentration of said anaerobic bioreactor 1 can be maintained.

In another embodiment of the system 10, wherein said anaerobic bioreactor 1 and  
aerobic bioreactor 2 are initially seeded with anaerobic sludge and aerobic sludge  
respectively; said membrane separation reactor 3 comprise a device for recycling  
15 microbes from said membrane separation reactor 3 to said aerobic bioreactor 2.  
Furthermore, said aerobic bioreactor 2 and membrane separation reactor 3 can further  
comprise a device for discharging excessive aerobic waste sludge into anaerobic  
bioreactor 1 and proceeding the reaction of anaerobic digestion; said aerobic waste sludge  
can further pass through an alkaline sludge hydrolysis apparatus 5 before being discharged  
20 into the anaerobic bioreactor 1. Otherwise, said anaerobic bioreactor 1 can further  
comprises a device for discharging sludge outside the anaerobic bioreactor.

In the system for treating wastewater containing organic compounds 10 provided  
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herein, the microbes of said anaerobic bioreactor 1 and aerobic bioreactor 2 can further comprise denitrifying microbes. If necessary, an aerobic pretreatment device 4 can be further arranged upstream of anaerobic bioreactor 1 for removing toxic organic substances in wastewater; membrane separation reactor 3 can further comprise a gas sparging device  
5 for scouring membrane.

Carbon dioxide is a major by-product of anaerobe metabolism and leads to increase the carbonate concentration of water. When Ca, Mg, Fe or other metal ions existing, scaling of metal carbonate is prone to form on membrane surface, causing the membrane obstruction. In the system of present invention, the effluent of anaerobic  
10 bioreactor 1 flows into aerobic bioreactor 2 where the residual organic pollutants of said effluent would be eliminated by aerobes therein, and the dissolved inorganic ions of said effluent produce crystals or inorganic solids under high pH value in the aerobic bioreactor 2. The air stripping that may increase 1-2 unit of pH value after aeration causes the high pH value of the aerobic bioreactor 2. Furthermore, such crystals or solids are inserted in  
15 the floc matrix of aerobes through bioflocculation, decreasing the formation possibility of scaling on the membrane of said membrane separation reactor 3. When the effluent of aerobic bioreactor 2 flows into membrane separation reactor 3, the membrane would be scoured with biogas. Scouring with biogas can lower the pH value of water by 0.2-1.0 units and further prevent the formation of scaling on the membrane surface. If necessary,  
20 membrane can be scoured with air and work together with inorganic acid (e.g. HCl) to reduce the pH value of membrane separation reactor 3 or membrane can be scoured optionally with air only, those are for the purpose of preventing scaling.

Fig. 2 is the flow chart of the method for treating wastewater containing organic compounds, which comprises the following steps: (a) to begin with, feeding wastewater containing organic pollutants into an anaerobic bioreactor where the anaerobes therein decompose said organic pollutants and produce methane and carbon dioxide; (b) subsequently, feeding effluent of anaerobic bioreactor in step (a) into an aerobic bioreactor, where the aerobes therein decompose the residual organic in wastewater and carbon dioxide dissolved in water is stripped by air stripping effect that increases the pH value of water, whereby the crystals of metal carbonate, struvite and inorganic solids are produced and inserted in the floc matrix of aerobes through bioflocculation; and (c) feeding effluent of aerobic bioreactor in step (b) into a membrane separation reactor where solids in the water are separated from liquids to acquire effluents free of organic pollutants.

The aforesaid method for treating wastewater containing organic compounds can further include a denitrification procedure in step (a), and/or include a step of pretreating wastewater for removing the toxic substances (e.g. phenols and aldehydes) before step (a). Said method can also comprise a step of alkaline hydrolysis for aerobic waste sludge in an alkaline sludge hydrolysis apparatus before step (a), enhancing the hydrolysis of aerobic wastewater and the digestion capability of anaerobic sludge. Furthermore, said method can comprise a step of recycling microbes from the aerobic bioreactor and membrane separation reactor to the anaerobic bioreactor so that the concentration of microbes can be controlled within a stable range and the costs could be reduced. Otherwise, said method can further comprise a step of scouring membrane of said membrane separation reactor by

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biogas sparing or scouring membrane with either air or air plus inorganic acid, lowering the pH value of said membrane separation reactor and preventing the scaling formation on the membrane surface.

The advantages of the present invention are further depicted with the illustration of an example, but the descriptions made in the example should not be construed as a limitation on the actual application of the present invention.

### **Example**

The system used in the present example comprises an anaerobic bioreactor 1, aerobic bioreactor 2 and a membrane separation reactor 3 as shown in Fig. 1. The working volume of anaerobic bioreactor is 54 L; that of aerobic bioreactor is 16 L and that of membrane separation reactor is 6 L. The anaerobic granule sludge from a food UASB reactor is crushed with blender and then used as seed sludge. Both anaerobic bioreactor and aerobic bioreactor are initially seeded with that sludge. Microbes that can decompose organic substances in the aerobic bioreactor are facultative bacteria. Membrane used in the system is submerged ultrafiltration and gas used for aeration is biogas. The system is equipped with three peristaltic pumps for pumping untreated water, recycling sludge of aerobic bioreactor and membrane separation reactor, and effluent of membrane separation reactor respectively. The recirculation ratio of the system is 3.

Glucose and sodium acetate are used as artificial substrate for testing. The system is operated in continuous mode and the pH value and oxidation reduction potential (ORP) in anaerobic bioreactor as well as dissolved oxygen (DO), pH value and ORP in aerobic bioreactor are detected.

During two months of preliminary testing, the chemical oxygen demand (COD) of anaerobic bioreactor ranges between 12,000~ 18,000 mg/L and influent volume is 8.6 L/day. The testing results are shown in Fig. 3. Fig. 3 shows the relationship between COD concentration and operation days in the influent of anaerobic bioreactor, effluent of anaerobic bioreactor and effluent of membrane separation reactor. The COD concentration of anaerobic effluent ranges between 1,000 ~ 2,100 mg/L, while that of membrane separation reactor effluent, the membrane permeate, ranges between 50 ~ 70 mg/L. Such results illustrated that the system for treating wastewater containing organic compounds of the present invention works effectively, in which the organic pollutants in the wastewater are decomposed by the anaerobes and aerobes and the system has maintained its disposal capability for organic pollutants even after working for two months.

To identify the environmental conditions of anaerobic bioreactor and aerobic bioreactor, the pH and ORP value of anaerobic bioreactor effluent, pH, DO and ORP in aerobic bioreactor, and pH value in membrane separation reactor were recorded regularly. Those results are shown in Fig 4, Fig 5 and Fig 6. Fig. 4 is the monitoring results of pH and ORP in anaerobic bioreactor; Fig. 5 shows the monitoring results of pH, ORP and DO in aerobic bioreactor; and Fig. 6 is the comparison between anaerobic bioreactor, aerobic bioreactor and membrane separation reactor for the pH value. As shown in Fig. 4, the pH in anaerobic bioreactor was stable and maintained between 7.3 and 7.6; ORP was maintained between -220 ~ -320 mV. Though there was fluctuation in the ORP value, the environment remained absolutely anaerobic condition. As shown in Fig. 5, DO in aerobic

bioreactor was controlled between 2 ~ 4 mg/L which satisfied the demand of aerobic metabolism. Fig. 5 also shows that the pH in aerobic bioreactor rose to 8.6 ~ 8.9 due to the high concentration of carbonate in effluent of anaerobic bioreactor. During aeration, air stripping increased the pH value. The elevated pH value enhanced the tendency toward  
5 crystal formation of metal ions. Fig. 5 also shows the significant fluctuation of ORP in aerobic bioreactor, the ORP ranged between -10mV and -120mV though DO in the water reached 2 ~ 4 mg/L, indicating that active reduction was going on in aeration reactor. This means that the system was still capable of decomposing organic pollutants even after two months of operation. Fig. 6 shows that the pH in anaerobic bioreactor was 1-2 units lower  
10 than that in aerobic bioreactor, while the pH in aerobic bioreactor was 0.1-1.5 units higher than that in membrane separation reactor.

In the system for treating wastewater containing organic compounds provided herein, the microbes for decomposing organic pollutants used in anaerobic bioreactor are methanogens and facultative anaerobes, and those used in aerobic bioreactor are facultative anaerobes. Thus the microbes in aerobic bioreactor could be circulated to anaerobic bioreactor. In the aerobic bioreactor, the pH value of water is increased while removing organic pollutants, and inorganic crystals are inserted into the floc matrix of microbes through bioflocculation, reducing the tendency of scaling formation on membrane surface. Otherwise, the membrane is scoured with bio-gas or air plus inorganic acid to lower the pH value in membrane separation reactor, or scoured with air only. Those reduce the membrane scaling and achieve the purpose that prolonging the usage life of the membrane.